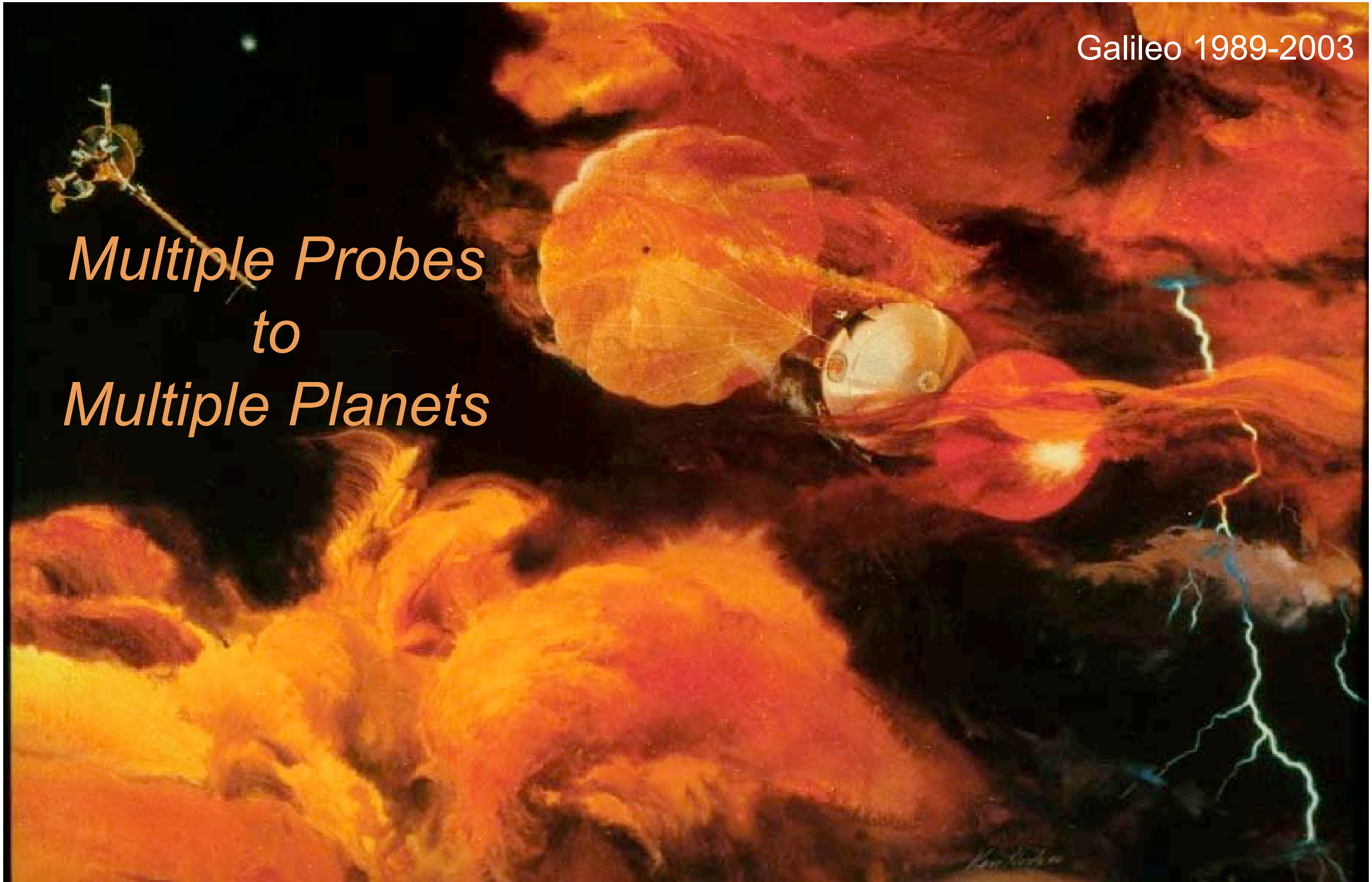
Multiple Probes to Multiple Planets



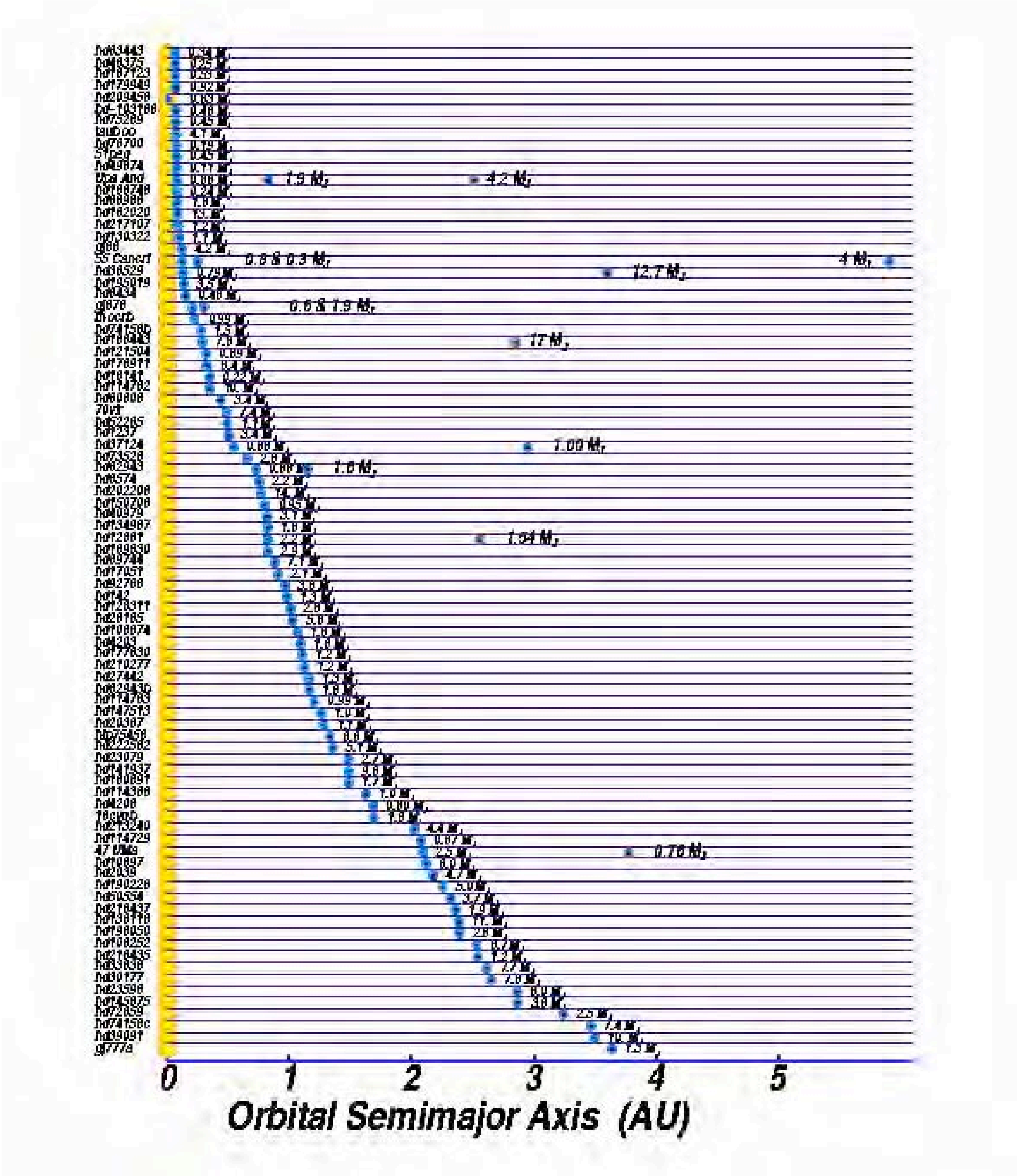
Sushil Atreya   Toby Owen

plan

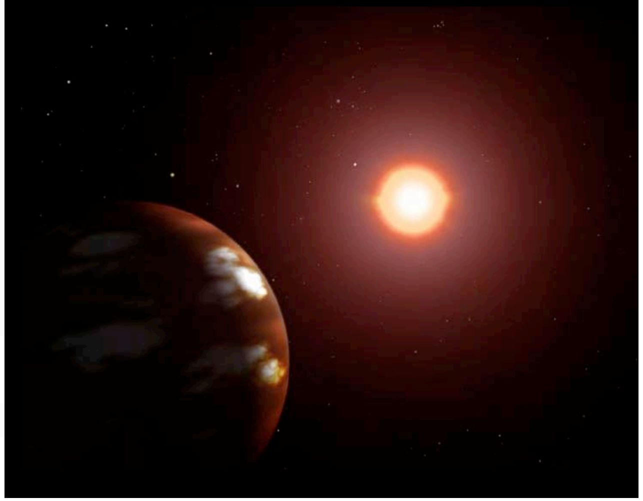
Why bother with giant planets?

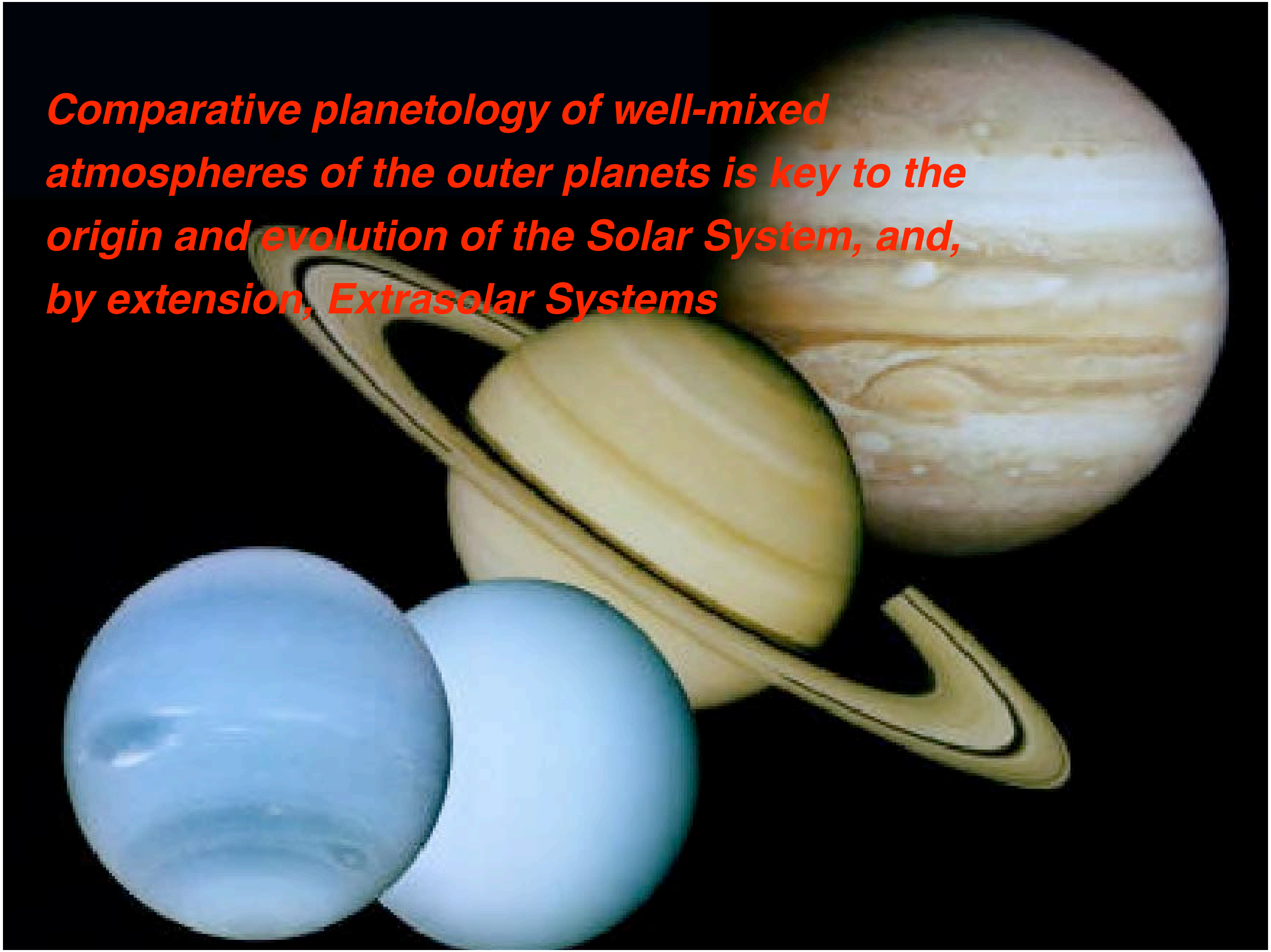
- **Jupiter: what's missing? what to do?**
- **Saturn: post Cassini-Huygens**
- **Uranus and Neptune: ?????**

Probes: why and where?



Extrasolar Giant Planets (EGP)




Comparative planetology of well-mixed
atmospheres of the outer planets is key to the
origin and evolution of the Solar System, and,
by extension, Extrasolar Systems

Origin of Jupiter's atmosphere

***Gravitational instability: Protoplanetary clumps**

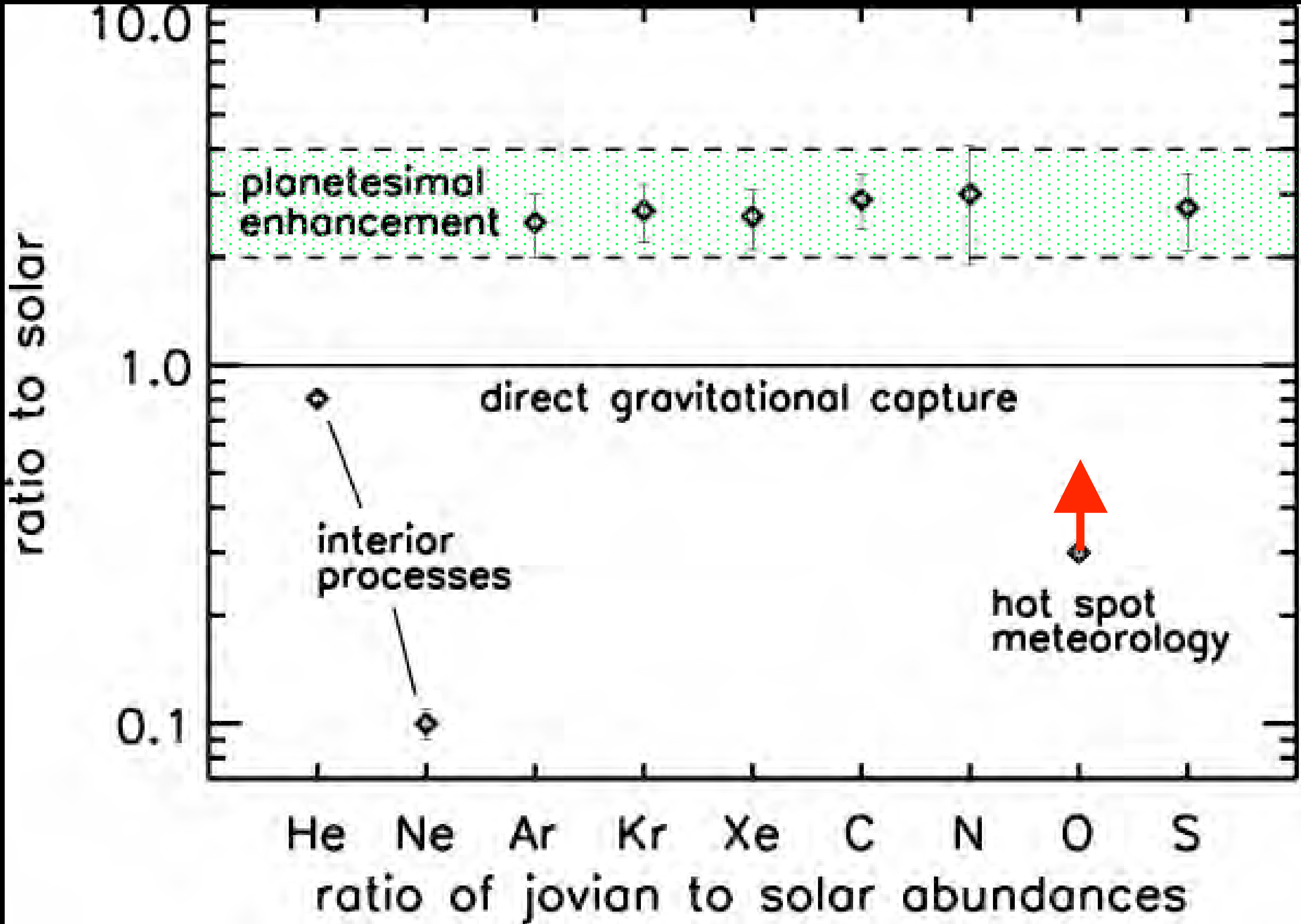
***Core accretion model**

- Core from grains of ice, rock, metal
- Core grows to critical mass (~10 M_E)
- Gravitational collapse: H_2, He (most volatile gases) captured
- Atmosphere from H_2, He; and volatiles released from core
- Planetesimals added throughout the formation (and afterward) to explain heavy element enrichment
  - Cold icy planetesimals
  - Clathrate hydrates, "cold", nevertheless

Origin: what must be known?

abundances of "heavy elements" in "well-mixed" atmosphere

Elemental abundances at Jupiter
(Galileo Probe Mass Spectrometer, GPMS)

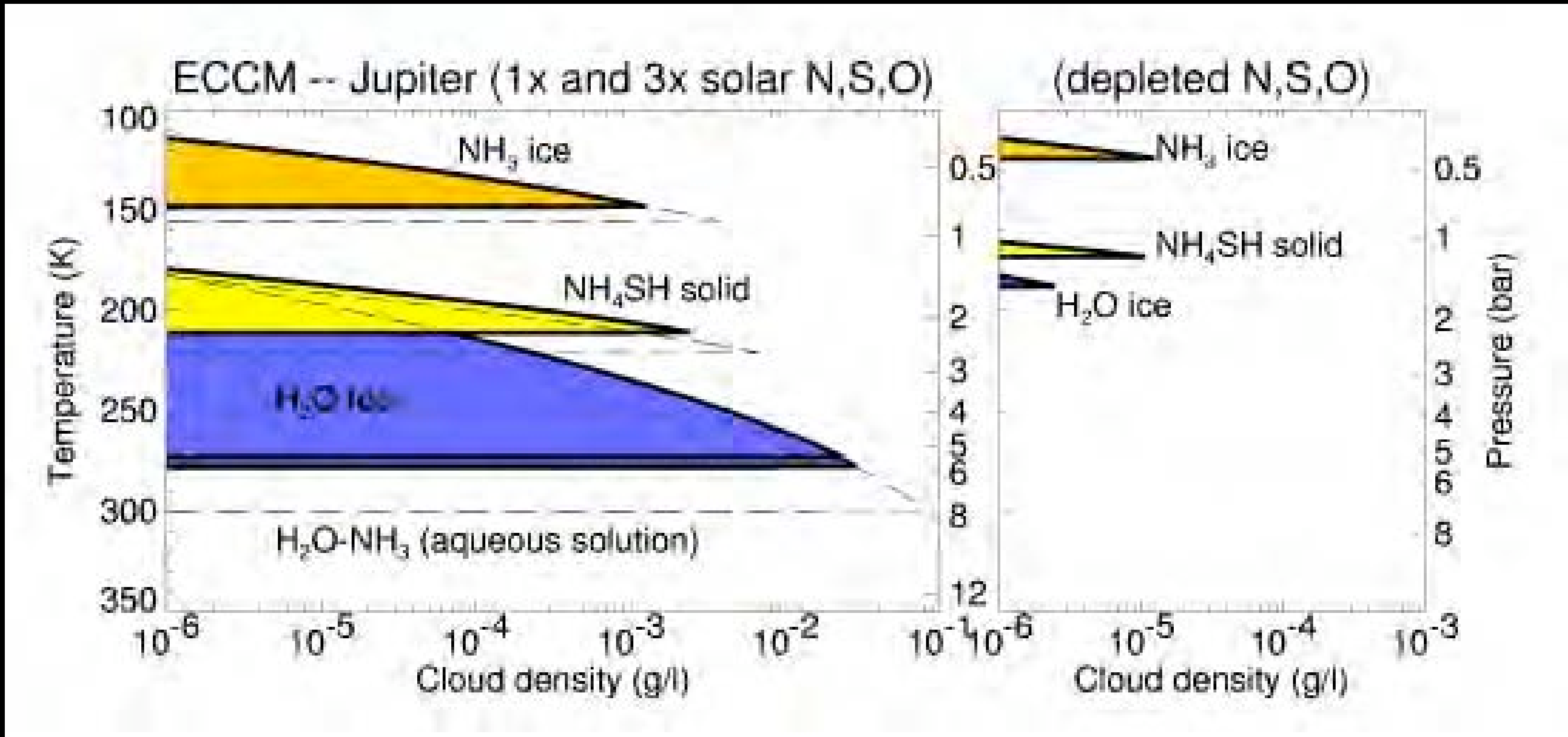


Cylindrical Maps of Jupiter: 1° S – 14° N

NASA Infrared Telescope Facility

Middle Infrared Array Camera: 4.8μm

Jupiter clouds

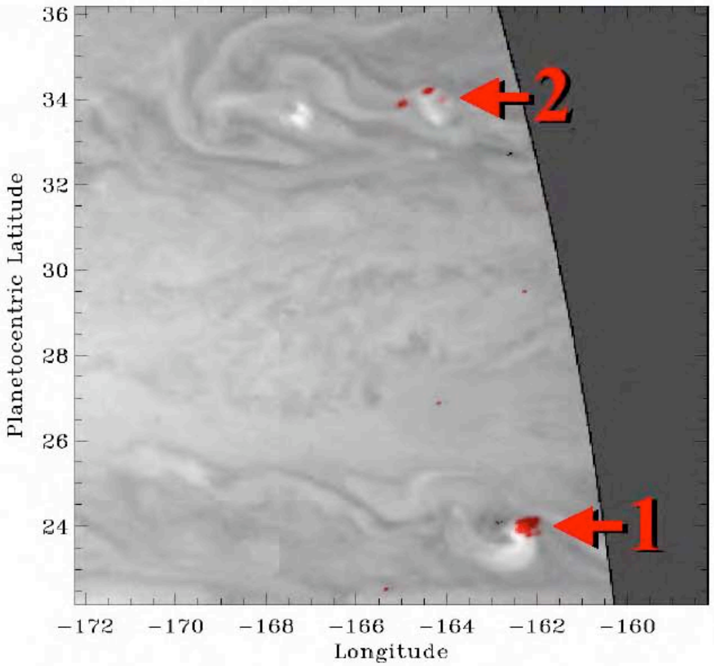


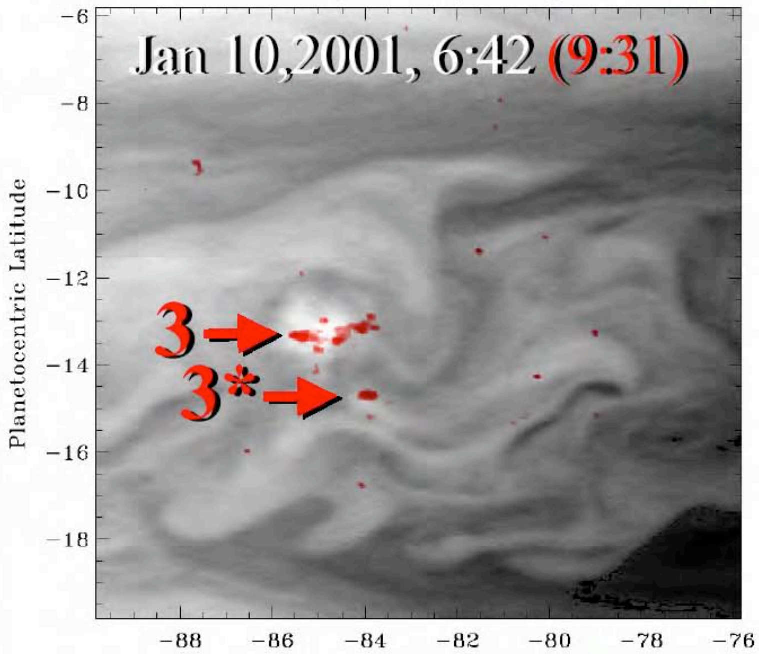
Equilibrium **Hot Spot**

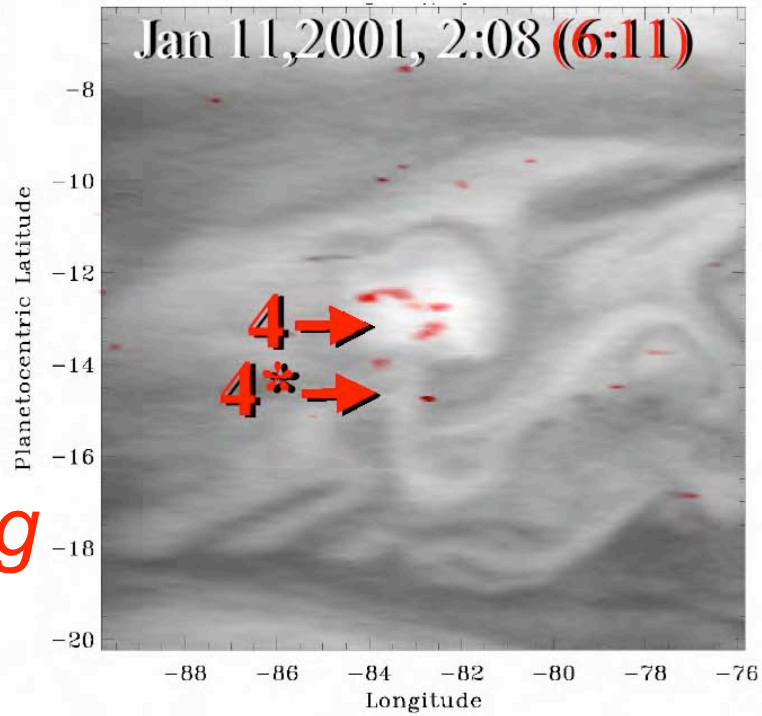
Day side clouds and

night side lightning

Jan 1,2001, 6:37 (8:21)





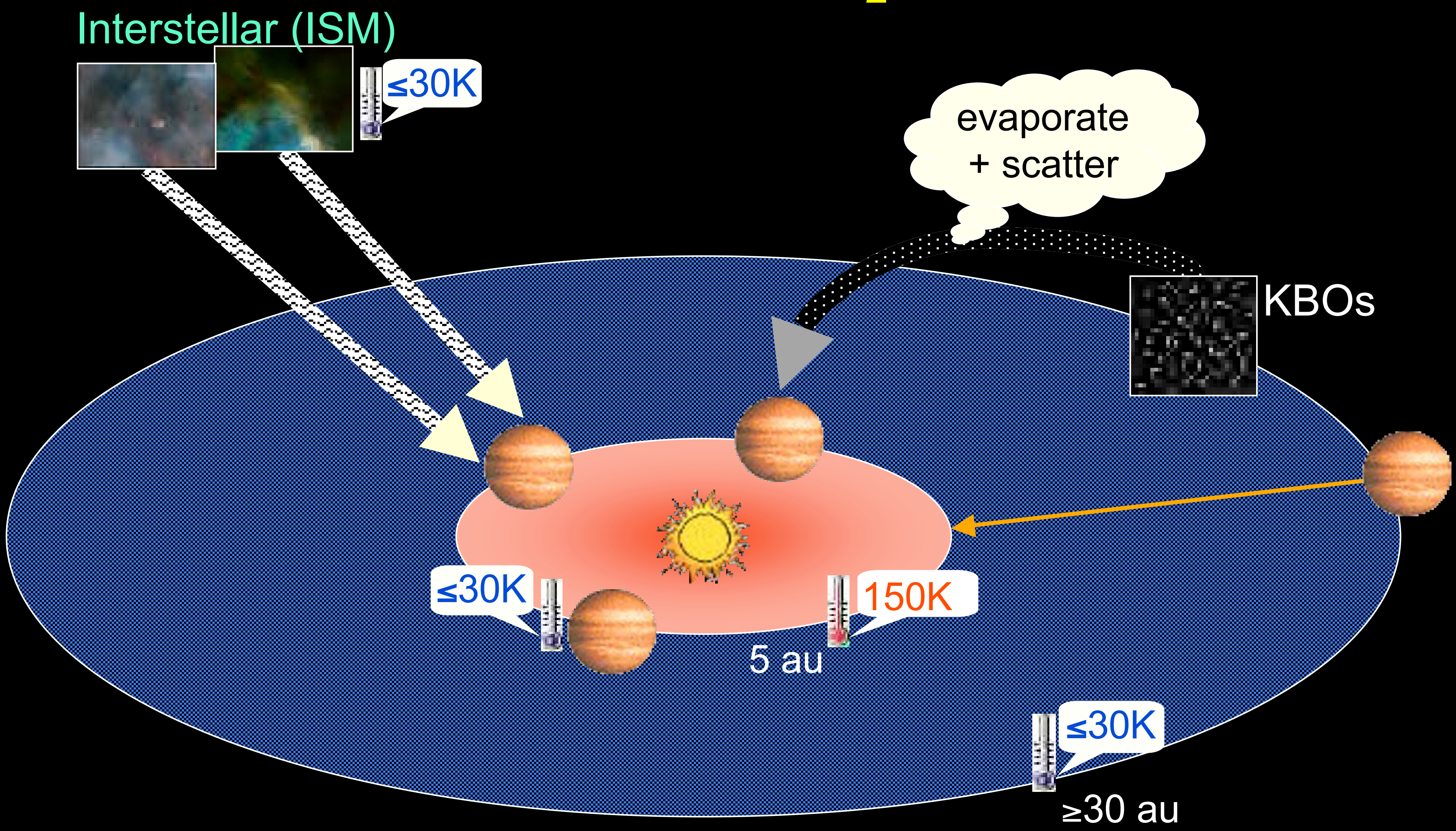


Cassini Imaging

(140 R_J=10 Mkm)

Cold planetesimals and heavy element enrichment
Requires T≤ 30 K to trap N_2 and Ar

2-4× solar H_2O



Origin: clathrate-hydrates

Cold planetesimals from interstellar cloud may not have survived the formation of solar nebula (high T)

- Clathrate hydrates trap volatiles containing heavy elements in the cooling, feeding zone of Jupiter
- Predicts 9× solar H_2O, with 100% efficiency of trapping in clathrates (Gautier *et al*., 2001)

What is missing?

Water

abundance in “well-mixed” atmosphere

H_2O is presumably the original carrier of heavy elements to Jupiter.

Probes at Jupiter

How deep?

- **Base of water cloud (5 - 12 bar) “minimum”, but**
- **Must go deeper, to ensure mixed atmosphere is “really” reached (variability in NH_3, H_2O; hotspots)**
- **Recommend at least 50 bars, preferably 100 bars**

Where?

≥ Three probes: equatorial, mid- and high-latitudes

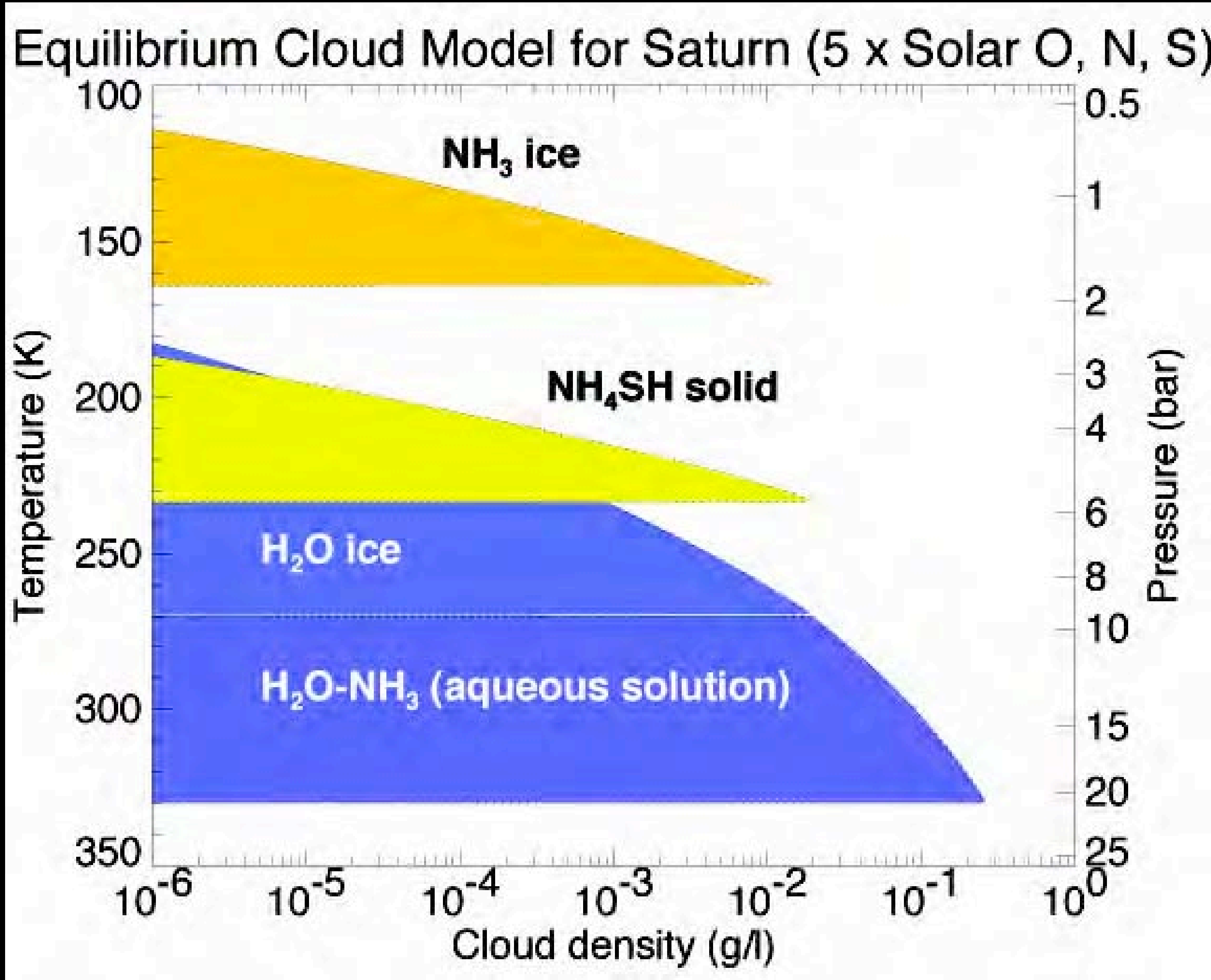
Cassini orbiter at Saturn

Measures stratospheric hydrocarbons

Heavy elements:
C/H = 6±1 x solar; P/H = 5-10 x solar (?)

but

- **No O, N, S, Ne, Ar, Kr, Xe, isotopes**
- **No deep atmospheric cloud or dynamics data**


Equilibrium Cloud Model for Saturn (5 x Solar O, N, S)
NH_3 ice
NH_4SH solid
H_2O ice
H_2O-NH_3 (aqueous solution)
Temperature (K)
100
150
200
250
300
350
Pressure (bar)
0.5
1
2
3
4
6
8
10
15
20
25
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Cloud density (g/l)

Probes at Saturn

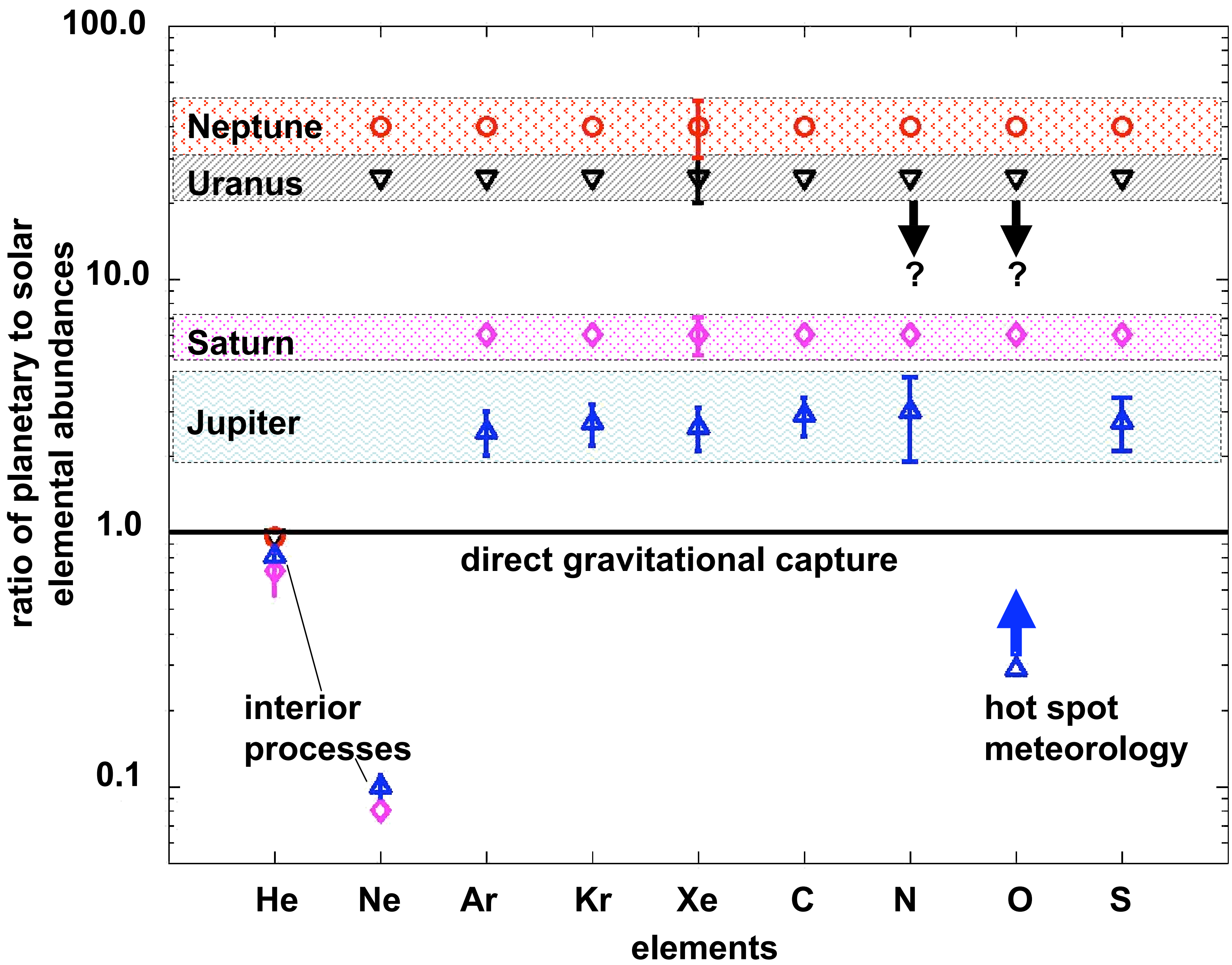
How deep?

- **Base of water cloud (25-45 bar) "minimum", but**
- **Must go deeper, to ensure mixed atmosphere is "really" reached (variability in NH_3, H_2O; warm areas)**
- **Recommend at least 50 bars, preferably 100 bars**

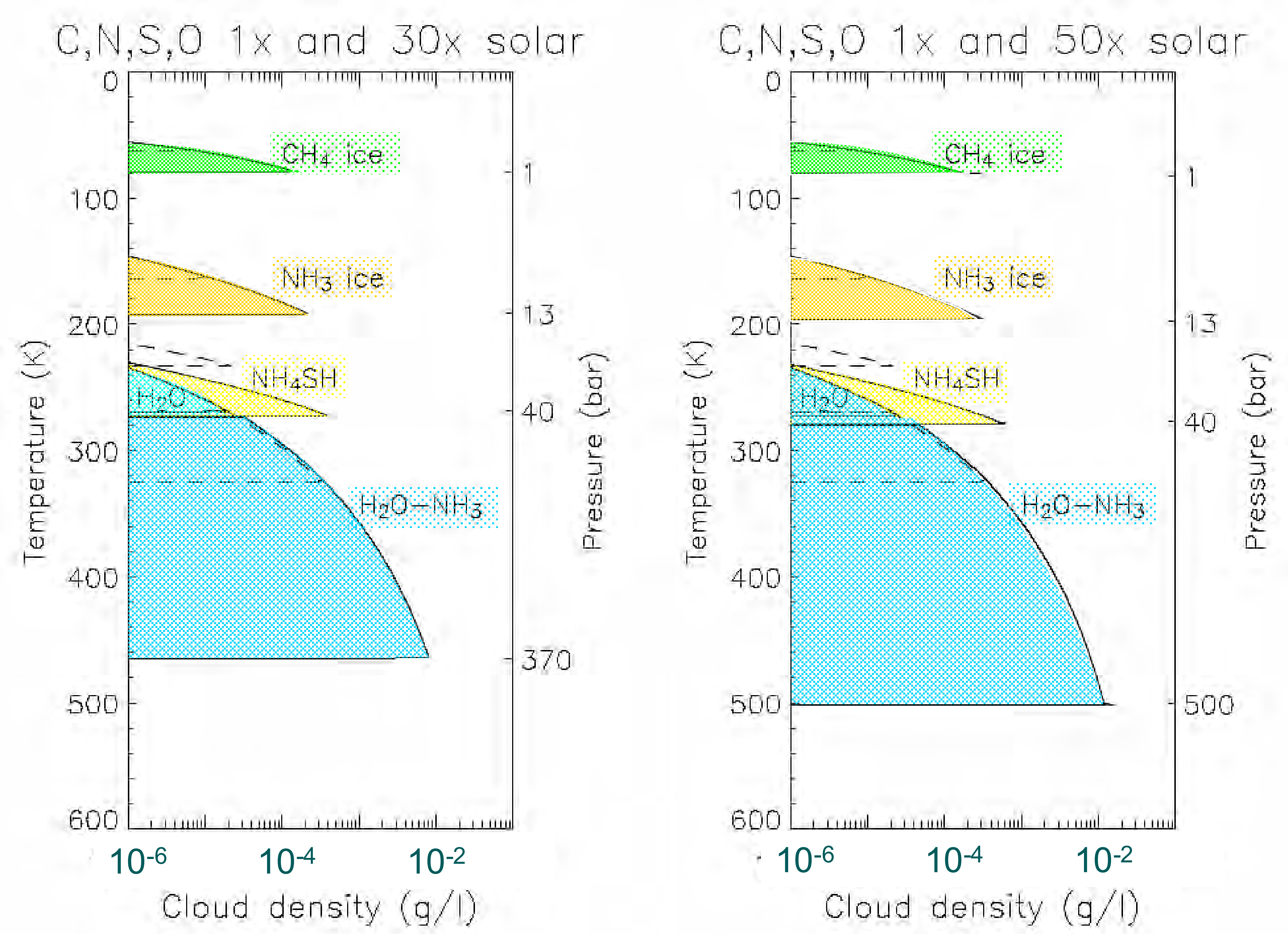
Where?

≥ Three probes: equatorial, mid- and high-latitudes.

Microwave radiometry would enhance probe mission


100.0
10.0
1.0
0.1
ratio of planetary to solar
elemental abundances
Neptune
Uranus
Saturn
Jupiter
?
?
direct gravitational capture
interior
processes
hot spot
meteorology
He
Ne
Ar
Kr
Xe
C
N
O
S
elements

Cloud model for Neptune



Summary

- Mixed atmosphere composition and related dynamics of gp, is <u>key</u> to solar system formation
- Probing to 50-100 bars at Jupiter and Saturn, yields <u>all</u> heavy elements, D/H, $^{14}N/^{15}N$, noble gas isotopes
- 10 bars at Uranus and Neptune, yields He, Ne, Ar, Kr, Xe, and C. 50 bars yields all these, plus S, N (?), 14N/15N, but not O — which is not critical.
- Enabling Technologies: TPS, RPS, Communications, Integrated Systems for high pressure-high temperature environments

MP^3 strategy

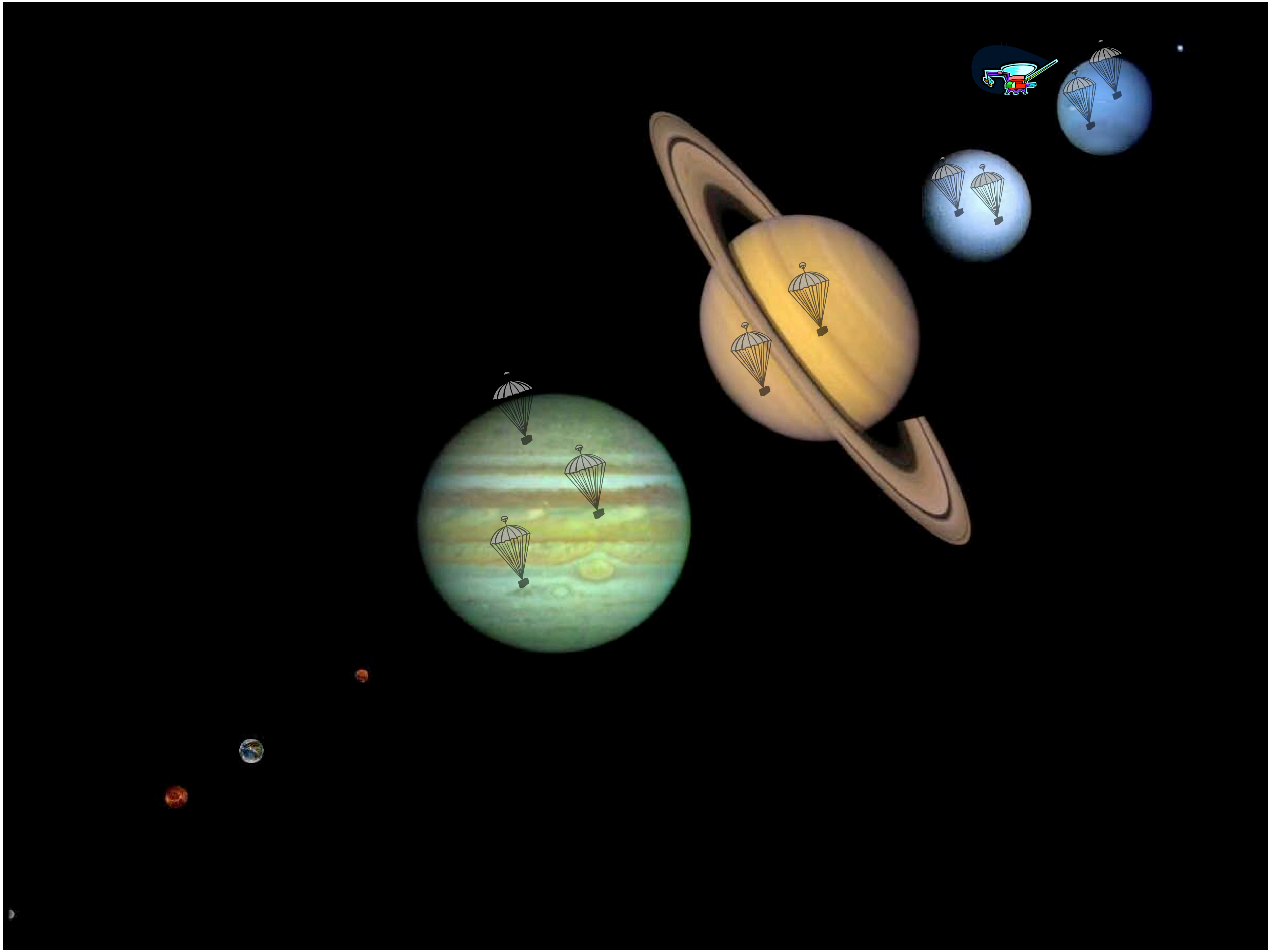
Multiple Probes to Multiple Planets with Multinational Partnerships

Program of one Probe mission every 7 -10 years

- **NF+ or fs, with Solar Power: Jupiter and Saturn**
- **NF+ or fs, with RPS: Uranus**
- **FS, with RPS: NPOP (Neptune Orbiter with Probes/ Triton Lander)**
- **Missions of opportunity, e.g. Europa orbiter**

**[NF+ enhanced New Frontier: 800 M$+; fs flagship: 800 - 1400M$;
FS Flagship: 1400 - 2800 M$]**

Multiple Probes at ALL giant planets!



Questions?

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Latest reference:

Atreya, S.K. and Wong, A.S., "…case for multiprobes", chapter in *Outer Planets* (T. Encrenaz, et al., eds.), Springer, 2005, pp 121-136.